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Controlling the Heat Transfer by Controlling the Composition of A Cooling Nano-fluid

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Abstract— **1) the first part of the present work is an experimental investigation of the convective heat transfer from a circular tube at constant wall heat flux. The working Nanofluid in these experiments is composed of alumina Nanoparticles, which are dispersed in water at concentrations of (0.0 %, 0.3 %, 0.5%, 0.7% and 1%), respectively, and this Nanofluid flows in a *hot* tube at *two* values of Reynolds number, Re_{nf} , 8676 and 13000.**

2) the second part is a *repetition* of the experiments of the first part, after Equipping the test rig with *a control unit*, which is designed to control the concentration of Nanoparticles in the base fluid, as required. The results from the two parts are compared as a reliability check for the designed control unit. The present work is intended to be *a step* towards a future work, in which, the experimental data of the variation of Nusselt number with the Nanoparticle concentration are fed to this control unit, in order to manage the thermal behavior of the large engine cooling systems, in order to meet the requirements of a specific application.

The results of the experiments showed an accepted agreement with the previous work, and the Nusselt number is possible to be effectively controlled, using the designed control unit.

Index Terms— **Control, Energy, Nanofluid, Nusselt.**

I. Introduction

In a wide range of applications, heat transfer augmentation was always the essential objective of many researchers and designers. One of the recent techniques of increasing the heat transfer is the addition of Nanoparticles to a base fluid to produce a Nanofluid, which is proved to be an efficient cooling fluid.

A. Nanofluids

The recent advances in Nanotechnology aided the production of particles with sizes on the order of Nanometers (Nanoparticles). The idea of suspending these Nanoparticles in a base liquid for improving thermal conductivity has been proposed recently[1]-[18]. Due to their small sizes, Nanoparticles are less likely to exhibit clogging, and sedimentation, or to cause erosion in tube walls, and, it is even possible to use them in micro channels. Since solid materials have much higher thermal conductivities than fluids, then, they could be added to fluids as suspended Nanoparticles to form slurries. Because of its minute sizes, the Nanoparticles move almost as if they are dissolved molecules in the base fluid, and thus, they "almost" move along the fluid stream lines. Many techniques are used to produce these Nanoparticles, for example; mechanical grinding and inert-gas-condensation techniques, chemical precipitation, chemical vapor deposition, micro-emulsions, thermal spraying, etc. Hamdi E. [1]. made numerical and experimental investigation to study the laminar heat transfer and fluid flow characteristics in an equilateral triangular duct using combined vortex generator and Nanofluids.he used Al_2O_3 and SiO_2 Nanoparticles, suspended in distilled water , and achieved significant heat transfer enhancement using compound vortex generators Azita Abdollahi and Mehrzad Shams, [2]. numerically investigated the effect of the Nanoparticles, vortex generator and combination of them on heat transfer and fluid flow characteristics in a rectangular channel. He found that, the Nusselt number increases by raising the Nanoparticles concentration and adding Nanoparticles is more effective than placing Vortex Generator from thermal point of view in the range of study. A.S. Navaei, , [3]. numerically, investigated the effects of different geometrical parameters and various Nanofluids on the thermal performance of rib–grooved channels under uniform heat flux. Using Al_2O_3, CuO, SiO_2 and ZnO . their results revealed that the semi-circular rib–groove with height of $0.2D_h$(8 mm) and pitch equals to 6e (48 mm) has the highest Nusselt number, and the Nanofluid containing SiO_2 has the highest Nusselt number compared with other types. N.A. Usri , [4]. investigated the effect of increasing Alumina Nanoparticles dispersed in 60:40 water to ethylene glycol based Nanofluids towards heat transfer enhancement. He concluded that, The heat transfer augmentation of Al_2O_3 Nanofluid at 0.6% volume concentration is higher than 0.2% and 0.4% concentrations. Hamdi E. Ahmed , [5]. investigated Al_2O_3 and SiO_2, as Nanoparticles suspended in distilled water. He showed that, using vortex generator with base fluid resulted in a good enhancement in heat transfer , and the maximum enhancement was registered when using the compound of vortex generator and Nanofluids with increase of the Nusselt number of about 44.64% and 41.82% at 1 vol.% and $Re \approx 4000$ for SiO_2–DW and Al_2O_3–(Distilled Water) Nanofluid, respectively. Zahra, [6]. investigated the forced convective heat transfer of water/functionalized multi-walled carbon Nanotube (FMWCNT) Nanofluid in a two-dimensional microchannel, under a periodic heat flux. She showed that local Nusselt number along the length of microchannel changes in a periodic manner and increases with the increase in Reynold number. Y.L. Zhai , [7]. experimentally investigated The characteristic of flow and heat transfer of Al_2O_3-H_2O Nanofluids flowing through a micro heat sink with complex structure under constant heat flux, he concluded that, With increasing volume fraction and Reynolds number, both Nusselt number, Nu and friction factor, f of Nanofluids increase while the average temperature at the bottom and thermal resistance decrease, as

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compared to deionized water.

W.H. Azmi , [8]. experimentally investigated The heat transfer coefficient and friction factor of TiO_2 and SiO_2 water based Nanofluids flowing in a circular tube under turbulent flow he concluded that a maximum enhancement of 26% in heat transfer coefficients is obtained with TiO_2 Nanofluid at 1.0% concentration, while SiO_2 Nanofluid gave 33% enhancement at 3.0% concentration, and the pressure drop is directly proportional to the density of the Nanoparticle. M. S. Hemeda, [9]. investigated the Nusselt number and friction factor for a heated tube which is cooled by a Nanofluid,(AL_2O_3/ water). The Nanoparticle concentrations, ϕ, equal 0, 0.3, 0.5, 0.7, and 1.0 %, respectively, and Reynolds number range from 8676 to 13000. He concluded that, the Nusselt number, $Nu = 0.1107\ Re^{0.7583}\ \phi^{0.1303}$.

B. Heat Transfer Enhancement with Nanofluids

almost all researchers, [1]-[18]. showed that; there is an enhancement in the heat transfer coefficient with increasing Reynolds number, the heat transfer coefficient enhancement increases with the decrease in Nanoparticle size, the heat transfer coefficient enhancement increases with increasing fluid temperature (more than just the base fluid alone), the heat transfer coefficient enhancement increases with increasing Nanoparticle volume fraction, and that is beside the thermal characteristics of both the Nanoparticles and the base fluid. the reasons for this extra enhancement in heat transfer with the decrease in particle size, may be the increase of a particle surface area, which is exposed to fluid, but on the other hand, decreasing the particle size decreases its heat capacity. in addition, increasing the particle concentration increases the heat transfer, but exceeding a certain concentration leads to a decrease in the fluid volume between particles which may leads to a decrease in the overall fluid heat capacity, which , in turn leads to a lower heat transfer rates. The conclusion is that; within a certain range of Reynolds number, the addition of Nanoparticles to a base fluid is expected to increase the Nusselt number over that , which is acheived with pure fluid. And thus, using this technique increases the heat transfer capabilities for the *same* Reynolds numbers, or , in other words, increasing the Nusselt number without the need to additional pumping power to increase the Reynolds number.

C. Objectives of the present work

The present work, consists of two parts;

1) an experimental investigation for the convective heat transfer from a circular tube at constant wall heat flux. The working Nanofluid in these experiments is composed of water and alumina Nanoparticles, which are dispersed in the water at concentrations of (0.0 %, 0.3 %, 0.5%, 0.7% and 1%), respectively, and this Nanofluid flows in the tube at *two* values of Reynolds number, Re_{nf} , which equal 8676 and 13000. These two values are expected to represent the lowest and highest values of the range of cooling rates for engine radiators in practice.

2) equipping the test rig with *a control unit*, which is designed to control the concentration of Nanoparticles in the base fluid. This control unit first is checked for reliability by comparing the results from the experiments of the first part with those from experiments with the same conditions, but with a controlled Nanoparticle concentration.

This group of experiments are intended to be a step towards a *future work*, in which, the data resulted from the experimental work of the first part, or the work of any other researcher, may be fed to the control unit , in order to manage the variation of Nusselt number according to a prescribed behavior, which may meet the requirements of a specific application, without the need to change the thermal conditions of the cooled surfaces, or to increase the power required for higher flow rates.

II. EXPERIMENTAL WORK

A. Test Rig

The first part of the experimental work is to investigate the variation of Nusselt number with the Nanoparticles concentration at two Reynolds numbers; 8676 and 13000. These experiments are performed using closed loop test rig shown in Figure 1. Al_2O_3 Nanoparticles of 50 nm size were synthesized, characterized and dispersed in water to form stable suspension of Nanofluid containing various concentrations of Nanoparticles which are; 0.0 %, 0.3, 0.5, 0.7 and 1%. These various concentrations of Nanofluid will be investigated at two values of Reynolds number, Re_{nf} ; 8676 and 13000. The main components of the test rig are; Two water pump, (P1, P2), of type, QB -60, (22 liters/min.), one of them is used to pump the working fluid from the cooling tank, T2, to enter the heated test tube, and exits to the collecting tank, T1, and the other pump is used to pump water from collecting tank to enter again the cooling tank. The water rates are measured by two rotameters, each of them is divided gradually from zero to 18 Liter/min. The water rates entering, either the test section or the cooling tanks, are controlled using bypass valves. Twenty five liters of water was used as a base fluid. A refrigeration cycle is mounted separately on a base to reduce vibration, and consists of a compressor of 1/3 hp, condenser, fan, expansion coil, and cooling coil, that is placed in the supply tank. A test circular copper tube is of 24 mm diameter , 2mm wall thickness and length of 2000 mm only 1000 mm was considered as test section, which is heated, under uniform heat flux condition, by means of an electrical coil wound around the wall of the testing pipe. The main and guard heaters are made of Nickel chromium heating coil with 1 mm diameter. The heaters are controlled via two variac transformers, model TDGC2-2kVA, each one has a maximum power of 1 kW, and its output voltage varies from 0 to 250V. The surface temperature has been measured by twenty two thermocouples made of copper-constantan (T-type). Also there are three pairs of similar thermocouples were fixed opposed to each other at equal distance on the two sides of the thermal insulation, to check for steady state conditions and to measure the heat lost to ambient air. Additional two thermocouples are set to measure the inlet and exit working fluid temperature. The signal outputs of the thermocouples were detected by thermometer indicator, model DT80-TENMARS thermometers which has resolution of ± 0.1ºC.

Fig. 1 Photograph for the experimental set-up

B. The Control Unit

In addition to the above test rig, a control unit, fig. 2, is prepared to control the concentration of Nano-particles in water, according to a prescribed requirements. It consists of ;

1 - Three additional tanks, (T3, T4, and T5). Tank,T3, is filled with 15 liters of a Nanofluid with the smallest concentration, (0.3%), tank,T4, is filled with 15 liters of a Nanofluid with concentration, which is higher than the maximum required concentration, (1.1 %). Tank, T5, is empty, and it participates in controlling the Nanofluid concentration when the solenoid valve, S3, which is on the exit pipe from test section, closes, and its solenoid valve, S4, opens.This actions allow tank, T5, to receive the drained fluid from the collecting tank, T1 .

2 – A third pump, (P3, maximum discharge of 6 liters/min.) is capable of sucking the Nanofluid from any of the two Nanofluid tanks, (T3, T4). Each of them is connected to a third pump, P3, through a pipe controlled by a solenoid valve , (S1 for T3, and S2 for T4), If one of them is chosen to supply a certain amount of Nanofluid, its valve opens , and the valve of the other tank closes. The supply *time* of any of the two tanks is proportional to the required amount.

3 – An Arduino uno is connected to the computer through a standard USB cable (A plug, 5V to B plug, ground). This arduino is programmed to switch the pump, P3, and the solenoids, (S1, S2, S3, and S4) ON and OFF for prescribed time periods, in order to control the mixing process and to achieve the required concentrations. Figure 2 illustrate a schematic diagram for the control unit and its connection to the test rig.

C. Experimental Considerations

First of all, Al_2O_3 Nanoparticles are dispersed in water without using any dispersant or stabilizer to prevent any possible changes of chemical properties of the Nanofluid. The mass of Nanoparticles required for each concentration is dispersed in water using ultrasonic vibrator for 5 hours.The prepared Al_2O_3/water Nanofluid was determined by SEM (Scanning Electron Microscope JSM 6360SEM).

The following steps are followed for each test run;

1) The fluid leakage was checked, as the fluid flow circuit is switched on.

2) The main and guard heaters were checked by measuring the electric resistance for each one individually.

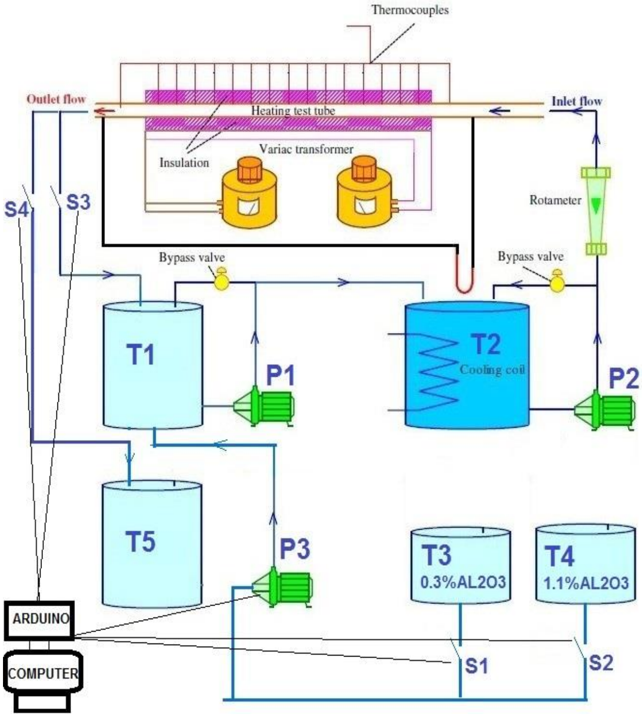

Figure 2 Installation Of The Control Unit

3) The input heating power is regulated by adjusting the variac transformer until the multimeter measure the required heat input to the fluid flow.

4) The input heating power of the guard heater was adjusted by raising its input voltage value each10 minute until the temperature difference between the insulation thermocouples pairs becomes close to zero as indication of no heat loss from the main heater to the surroundings.

5) Valves attached to Rotameter were adjusted to give the required flow rates as indicated by the Rotameter readings.

6) All the different readings are taken each 30 minutes until constant three successive readings are observed to be constant within ± 0.1ºC variation in the surface temperature. At this time the system is considered to be in a thermal steady state condition.

The following measurements were recorded when thermal steady state condition is achieved

- Readings of the three pairs of the insulation surfaces thermocouples are used to check the thermal equilibrium condition i.e. the steady state.
- Readings of the room temperature.
- Readings of the inlet and outlet fluid temperature at inlet and outlet of the test section respectively.
- Readings of the surface temperature twenty two thermocouples of the heated surface test tube

All data including the heat input, surface temperatures, inlet and outlet fluid flow temperature are fed to a computer spread sheet , to calculate Reynolds number, local and average heat transfer coefficients, Nusselt number, and enhancement ratio.

D. Experiments with a controlled concentration of Nanoparticles

The *second part* of the present work could be considered as a reliability check for the "*control unit*". In these experiments, it is required to "compare" the Nusselt number results of the experimental work of the first part with the resultsof the same experiments, but when the concentration of Nanoparticle is controlled by the control unit. For any one of the experiments, in which, the Nanoparticles concentration is controlled by the control unit , all the above steps are followed , beside the following additional preparations;

1- The collecting tank is filled with 25 liters of a Nanofluid with the smallest concentration, (0.3%)

2- The pump, P3, and the solenoid valves, S1 and S2 are closed, then, the bypass valves are adjusted and the rotameter is monitored until the steady state is achieved with the required Reynolds number.

3- Now, if we need a certain Nanoparticle concentration, (say $\phi = 0.5$ %); valve S3 is closed, and valve S4 is open, until the volume of the Nanofluid in tank T1 is reduced by a volume, ΔV ;

$$\Delta V = \frac{V_{T1}\ (\phi_{req} - \phi_i)}{(\phi_{add} - \phi_i)} \quad (1)$$

And this reduction in Nanofluid volume occurs during an interval of time, ti;

$$t_L = \frac{V_{T1}\ (\phi_{req} - \phi_i)}{Q_r\ (\phi_{add} - \phi_i)} \quad (2)$$

At the end of t_L , valve S3 is opened and valve S4 is closed. This reduction in T1 is compensated from one of the tanks, T3 or T4; depending on if we need to decrease or increase the current concentration. So, if we need to increase the concentration, open valve S2 and close S1, and vice versus, then operate pump, P3, for an interval of time t_C, where,

$$t_C = \Delta V / Q_{P3} \quad (3)$$

At the end of t_C , pump P3 is switched off, and both S1 and S2 is closed

Where;

t_L , the time during which, the valve S4 will stay opened, while S3 is closed, to allow the removal of part of the fluid from tank, T1.

V_{T1} , the volume of the total fluid in tank, T1.

Q_r , the discharge read by the rotameter, m^3/s

ϕ_{req} the required Nanoparticle concentration.

ϕ_i the initial Nanoparticle concentration in the fluid, in the tank, T1.

ϕ_{add} the Nanoparticle concentration of the fluid, which is added to tank, T1.

T_C time, during which, pump, P3 is operated

Q_{P3}, the discharge of pump, P3, m^3/s

Note: the effect of changing the concentration while the fluid is circulated could be neglected, because;

- P1 actually sucks fluid from a layer in the tank, which is lower than the layer, where P3 pour the compensating fluid, so the two layers require time to mix
- Both t_L and t_C are relatively small, which decreases the probability of loosing considerable part of the *"mixed"* fluid to tank, T5

4- Again check the thermocouples on either sides of the insulation between the main and guard heaters and adjusting guard heater variac until a steady state is achieved, and taking the thermocouple readings , as in the experiments of first part.

E. Calculations of local and average heat transfer coefficients and Nusselt number

The heat supplied to the test section via the main heater is devided into three parts:

- q_{net} , Heat transferred by convection to the fluid in the tube (useful part)
- q_c , Heat lost by radial conduction through the insulation layers
- q_{axial}, Heat lost by the axial conduction through the surface

$$q_{net} = q - q_c - q_{axial} \quad (4)$$

The heat lost by the axial conduction through the tube wall, q_{axial}, and the heat lost by radial conduction through the insulation layers are found to be relatively small, and could be neglected. Then, he heat transferred from each unit area of the tube surface will be;

$$q'' = V^2 / (R^* \pi D_i\ L) \quad (5)$$

Heat gained by the fluid passing by a tube segment, j ;

$$q_j = \pi D_i\ L_j\ q''_j \quad (6)$$

$$q_j = m\ C(T_{o\,j} - T_{i\,j}) \quad (7)$$

equation 7 is used to estimate T_{oj} , and since, the fluid temperature entering the tube was measured before, then the exit fluid temperature from the first tube segment could be calculated, and used as inlet temperature to the next segment, and so on. From these local fluid temperatures, the local and average heat transfer coefficients could be estimated;

$$h_j = \pi D_i\ L_j\ (T_{s\,j} - T_{f\,j}) \quad (8)$$

$$h_{ave} = \frac{1}{L}\int_0^L h_j\, dL \quad (9)$$

$$Nu_{ave} = h_{ave}\ D_i / k \quad (10)$$

The total heat gained by the fluid

$$q = m^*\ C\ (T_s - T_f) \quad (11)$$

$$T_s = \frac{1}{n}\sum_{j=1}^{j=n} T_{sj}\ , \quad j = 1,..,n \quad (12)$$

Where;

m^* fluid flow rate, kg/ s

C specific heat of fluid, J kg^{-1} K^{-1}

V applied volt across the heater coil

R coil resistance

D_o tube inner diameter

L_j tube segment length

$T_{i\,j}$ segment inlet fluid temperature

$T_{o\,j}$ segment outlet fluid temperature

$T_{s\,j}$ local surface temperature, (measured by a thermocouple)

T_{fj} average of both, T_{ij} and T_{oj}

L : is the total length of the test section, m

h_j : is the local heat coefficient at segment, $Wm^{-2}K^{-1}$

h_{avg} is the average heat transfer coefficient, $Wm^{-2}K^{-1}$

Nu_{ave} is the average Nusselt number

T_f average of fluid temperature entering and leaving the tube

T_s average of surface temperature

F. Estimation of thermo-physical properties of Nanofluid

Density of Al2O3/water Nanofluid is

$$\rho nf = \phi\, \rho np + (1-\phi)\, \rho w \quad (13)$$

Where: ϕ is the volume Concentration of Nanoparticle

Its specific heat is;

$$(\rho C)\, nf = (1-\phi)\, (\rho C) + \phi\, (\rho C)\, np \quad (14)$$

The effective viscosity of Nanofluid μ_{nf} is;

$$\mu\, nf = (1-\phi)\, \mu w + \phi\, \mu np \quad (15)$$

And, according to, [17]. the thermal conductivity is;

$$\frac{k_{nf}}{k_w} = \frac{k_{np} + 2k_w + 2\phi(k_{np} - k_w)}{k_{np} + 2k_w - \phi(k_{np} - k_w)} \quad (16)$$

where,

k_{nf} is the thermal conductivity of the Nanofluid

k_{np} is the thermal conductivity of the Nanoparticle

k_w is the thermal conductivity of the base fluid; water

III. RESULTS AND DISCUSSIONS

The results of the first part of the present work, which relate the variation of Nusselt number to Nanoparticle concentration, for Reynolds numbers, Re_{nf} = 8676 and 13000, are shown in figure 3 and Figure 4, respectively. For the purpose of comparison, each one of the two figures also contains the following two relations; Xuan and Li, [18] ;

$$Nu = 0.1107\, Re^{0.7583}\, \phi^{0.1303} \quad (17)$$

And M. S. Hemeda, [9]. By using the multi-variable curve fitting, with careful trial and error, the experimental results of *the present work* could be fitted to;

$$Nu = 0.1002\, Re^{0.7703}\, \phi^{0.1505} \quad (18)$$

Figures 3 illustrates slightly higher values for the present work data than those of other previous work. That may be because the over estimation of heat which is transferred to flowing water after neglecting the losses, but, with higher Reynolds number, and accordingly, higher mass and heat rates, the effect of this neglected losses, decreases, as shown in figure 4.

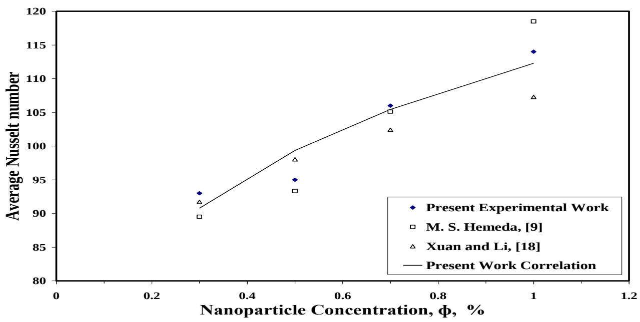

Figure 3. Variation Of Nusselt Number With Nanoparticles Concentration, for Re_{nf} = 8676

Figure 5. illustrates comparison of the data that are resulted by the classical experimental procedures and those resulted using the control unit, for Reynolds Number, Re_{nf} = 8676. It is obvious that, the data resulted

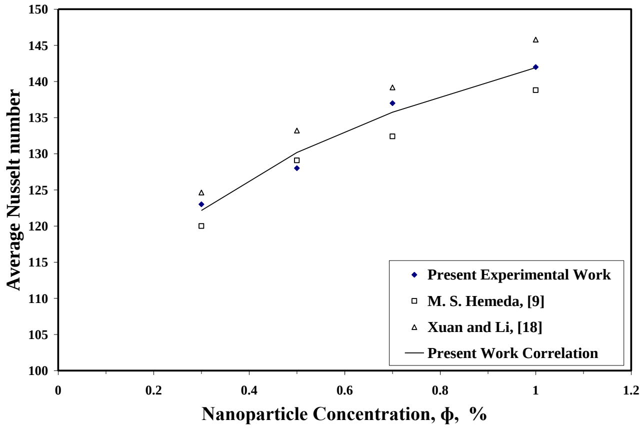

Figure 4. Variation Of Nusselt Number With Nanoparticles Concentration, For Re_{nf} = 13000

using the control unit are slightly higher than those resulted by the classic procedures. That is because, the valve does not response immediately, but after a finite time, whatever short. That is due to the relatively higher inertia of its moving parts, and its friction with the valve internal walls. And, these differences between data from the two procedures increase with Reynolds number. That is because of the increase in mass flow rate, which increase the error in the amounts of both; drained and supplied Nanofluids. However, this problem could be improved by using more advanced valves, whose material is lighter and has minimum internal friction.

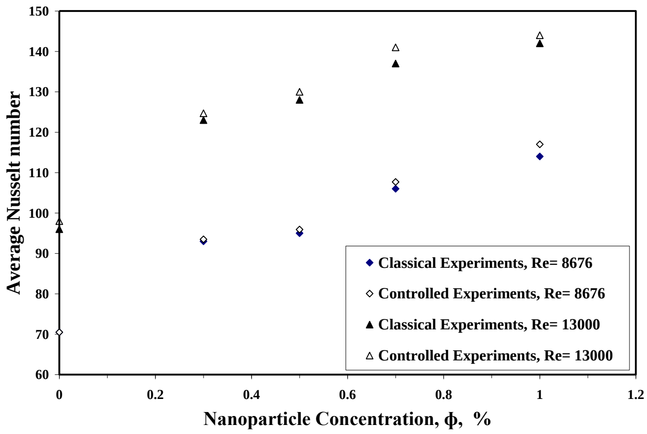

Figure 5. Comparison Of The Classical And Controlled Experimental Procedures

III. CONCLUSION

In the present work, experimental investigation of Nusselt number for a Al_2O_3 Nanofluid at concentrations of (0.0 %, 0.3 %, 0.5%, 0.7% and 1%), which flows in a *hot* tube at *two* values of Reynolds number, Re_{nf} , 8676 and 13000. Next, these classical experiments are repeated using a designed *control unit*, to control the concentration of Nanoparticles in the base fluid. The results from the experiments could be fitted to the correlation; $Nu = 0.1002\, Re^{0.7703}\, \phi^{0.1505}$

The results of the classical experiments showed an accepted agreement with the previous work, and the designed control

unit is proved to be capable of controlling the Nusselt number with an accepted effectiveness.

The present work is intended to be ***a step*** towards a future work, in which, the experimental data of the variation of Nusselt number with the Nanoparticle concentration, are fed to this control unit, in order to manage the thermal behavior of the large engine cooling systems.

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REFERENCES

[1] Hamdi E. Ahmed, M.I. Ahmed, M.Z. Yusoff, “Heat transfer enhancement in a triangular duct using compound Nanofluids and turbulators”, Applied Thermal Engineering, Volume 91, 5 December 2015, Pages 191-201

[2] Azita Abdollahi and Mehrzad Shams, “Optimization of heat transfer enhancement Nanofluid in a channel with winglet vortex generator”, Applied Thermal Engineering, Volume 91, 5 December 2015, Pages 1116-1126

[3] A.S. Navaei, “Heat transfer enhancement of turbulent Nanofluid flow over various types of internally corrugated channels” , Powder Technology, Volume 286, December 2015, Pages 332-341

[4] N.A. Usri , “Heat Transfer Augmentation of Al2O3 Nanofluid in 60:40 Water to Ethylene Glycol Mixture”, Energy Procedia, Volume 79, November 2015, Pages 403-408

[5] Hamdi E. Ahmed , “Experimental study of heat transfer augmentation in non-circular duct using combined Nanofluids and vortex generator” International Journal of Heat and Mass Transfer Volume 90, November 2015, Pages 1197–1206

[6] Zahra Nikkhah , “Forced convective heat transfer of water/functionalized multi-walled carbon Nanotube Nanofluids in a microchannel with oscillating heat flux and slip boundary condition”, International Communications in Heat and Mass Transfer, Volume 68, November 2015, Pages 69–77

[7] Y.L. Zhai , “Heat transfer enhancement of Al_2O_3-H_2O Nanofluids flowing through a micro heat sink with complex structure”, International Communications in Heat and Mass Transfer, Volume 66, August 2015, Pages 158–166

[8] W.H. Azmi , “Heat transfer and friction factor of water based TiO_2 and SiO_2Nanofluids under turbulent flow in a tube”, International Communications in Heat and Mass Transfer, Volume 59, December 2014, Pages 30–38

[9] M. S. Hemeda, “heat transfer enhancement in heat exchangers”, M.Sc thesis, mechnical engineering department, faculty of engineering, shobra, benha university, 2013

[10] Pooyan Razi, Akhavan-Behabadi, M.A., Saeedinia, M., “Pressure Drop and Thermal Characteristics of CuO–Base Oil Nanofluid Laminar Flow in Flattened Tubes under Constant Heat Flux”, International Communications in Heat and Mass Transfer vol.38, No 964–971, 2011.

[11] Özerinç, S., Kakaç, S., and Yazıcıoğlu, A. G., “Enhanced Thermal Conductivity of Nanofluids: A State-of-the-Art Review,” Microfluid. Nanofluid. vol. 8, No 2, pp. 145-170, 2010.

[12] Farajollahi, B., Etemad, S.Gh, Hojjat, M., “Heat Transfer of Nanofluids in a Shell and Tube Heat Exchanger”, International Journal of Heat and Mass Transfer, vol. 53, No 12–17, 2010.

[13] Chandrasekar , M., Suresh, S., Chandra Bose , A., “Experimental Studies on Heat Transfer and Friction Factor Characteristics of Al2O3/Water Nanofluid in a Circular Pipe Under Laminar Flow with Wire Coil Inserts”, Experimental Thermal and Fluid Science vol. 34, No 122–130, 2010.

[14] Fotukian, S.M., Nasr Esfahany, M., “Experimental Investigation of Turbulent Convective Heat Transfer of Dilute Al2O3/Water Nanofluid inside a Circular tube”, International Journal of Heat and Fluid Flow, vol. 31, No 606–612, 2010.

[15] Fotukian, S.M., Nasr Esfahany, M., “Experimental Study of Turbulent Convective Heat Transfer and Pressure Drop of Dilute CuO/Water Nanofluid inside a Circular Tube”, International Communications in Heat and Mass Transfer, vol.37, No 214 –219, 2010.

[16] Chandrasekar , M. , Suresh ,S., Chandra Bose, A., “ Experimental Studies on Heat Transfer and Friction Factor Characteristics of Al2O3/Water Nanofluid in a Circular Pipe under Laminar Flow with Wire Coil Inserts”, Experimental Thermal and Fluid Science , vol .34, No 122–130, 2010.

[17] Chandrasekar , M. , Suresh ,S., Chandra Bose, A., “ Experimental Studies on Heat Transfer and Friction Factor Characteristics of Al2O3/Water Nanofluid in a Circular Pipe under Laminar Flow with Wire Coil Inserts”, Experimental Thermal and Fluid Science , vol .34, No 122–130, 2010.

[18] Xuan, Y., and Roetzel, W., “Conceptions for Heat Transfer Correlation of Nanofluids,” International Journal of Heat and Mass Transfer, vol. 43, No 19, pp. 3701-3707, 2000